

Energy dependent forward $B \rightarrow J/\psi$ measurements in p+p collisions at PHENIX

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For the PHENIX Collaboration

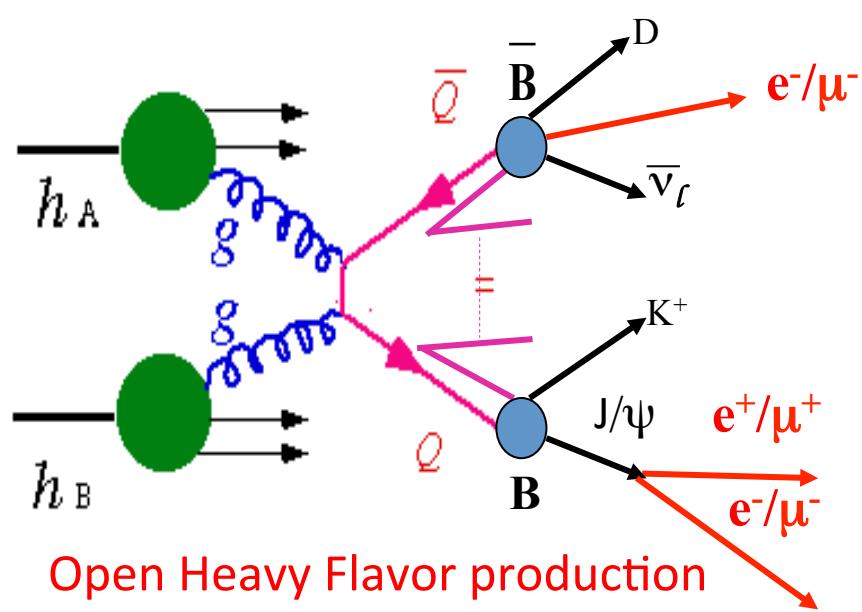
The logo for the 25th International Workshop on Deep Inelastic Scattering and Related Topics (DIS 2017) features a large, stylized, three-dimensional text "DIS" in blue and black. The letter "I" is partially obscured by a grey illustration of the Elizabeth Tower (Big Ben) from a low angle. To the right of the tower, the number "17" is displayed in blue. To the right of the logo, the text "25th International Workshop on Deep Inelastic Scattering and Related Topics" is written in blue, and below it, the dates "3-7 April 2017" and location "Birmingham, UK" are also in blue.

Outline

- Motivation.
- PHENIX and the Forward Silicon Vertex Detector (FVTX).
- PHENIX Forward $B \rightarrow J/\psi$ measurements:
 - in 510 GeV ([arXiv:1701.01342](#)) and 200 GeV p+p ([arXiv:1702.01085](#)) collisions to study the energy dependent B hadron production.
 - Extrapolated bottom cross section and comparison with NLO pQCD calculations.
- Summary and Outlook.

Motivation

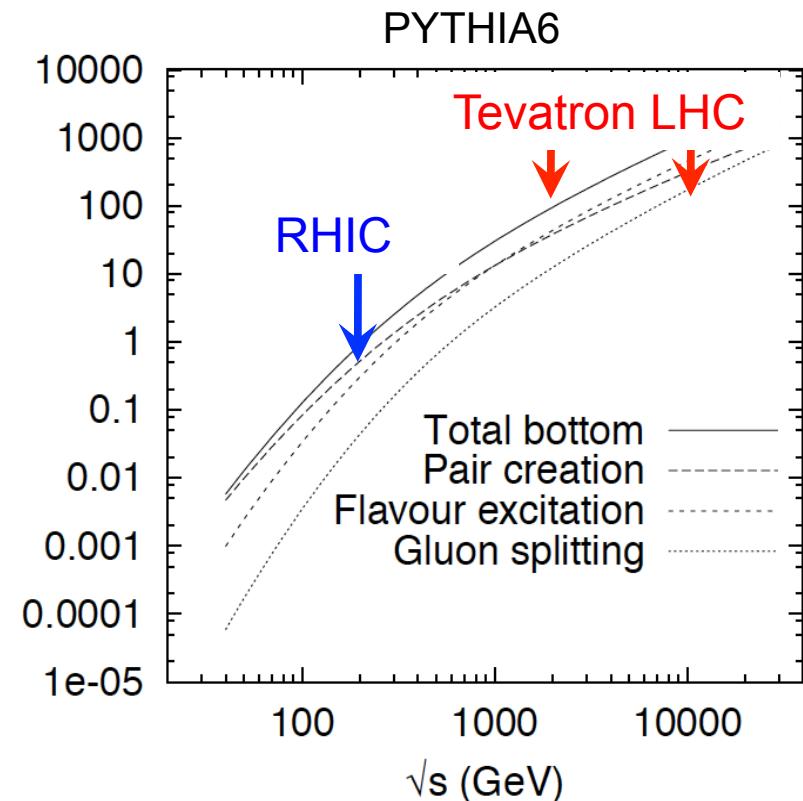
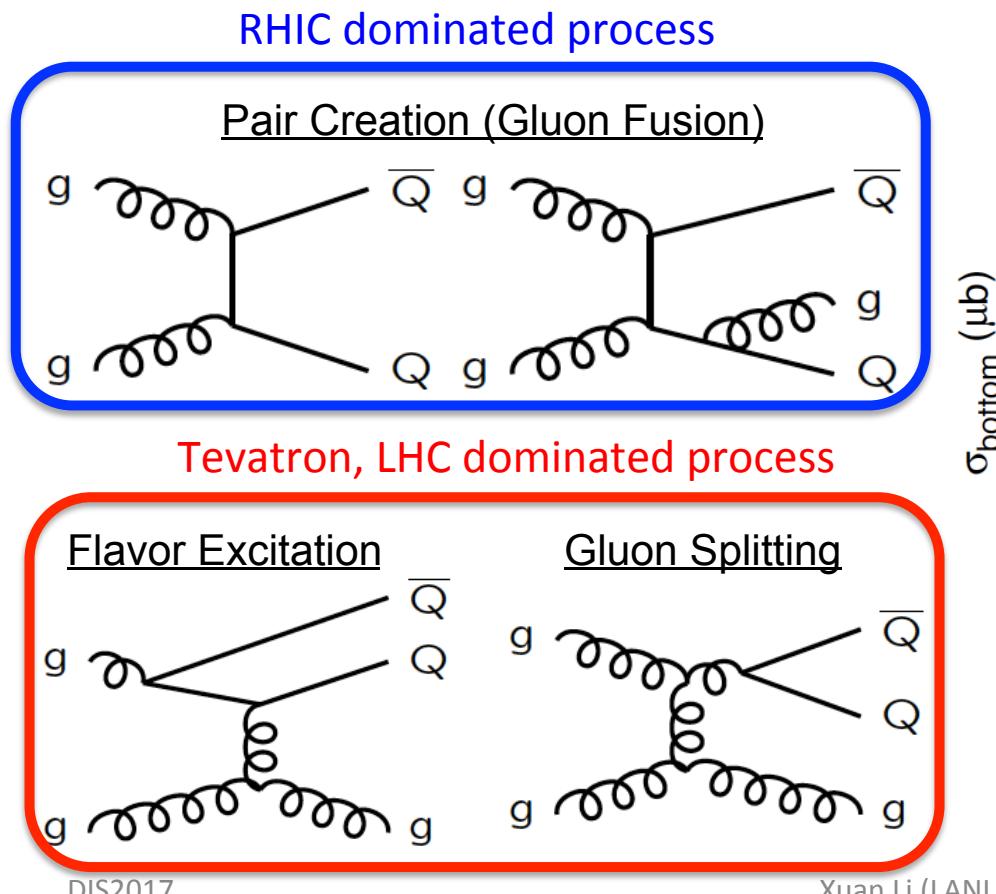
- Experimentally explore the heavy flavor production in a broad transverse momentum and energy to test QCD down to the non-perturbative region.
- Measurements in p+p collisions are essential to understand the nuclear modification of heavy flavor probes in heavy ion collisions.



- Inclusive Heavy flavor semi-leptonic decay measurements at RHIC are in agreements with NLO pQCD calculations.
- Measure B hadron directly at RHIC?
 - $B \rightarrow J/\psi \rightarrow \mu^+\mu^- (e^+e^-)$

Uniqueness at RHIC (I)

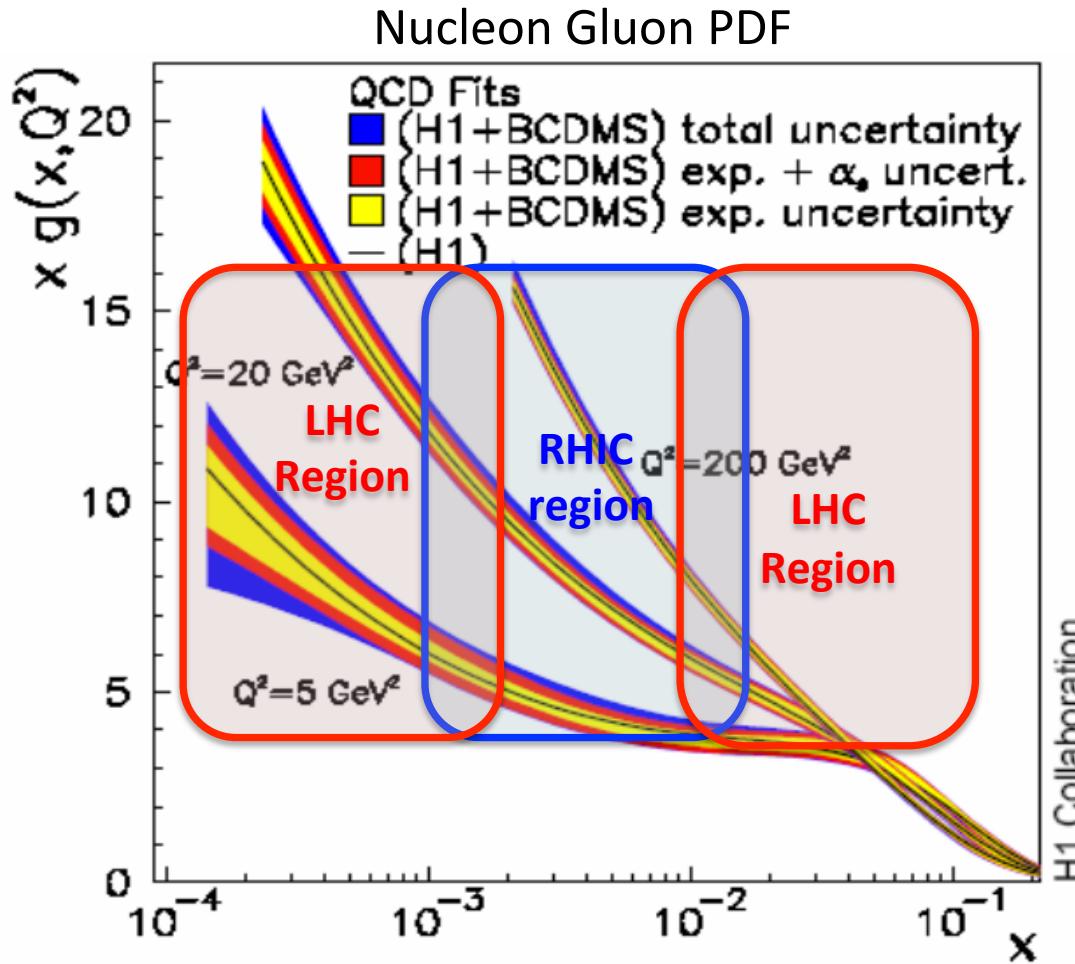
- Uniqueness at RHIC
 - Bottom production is dominated by pair creation (gluon-gluon fusion), clean interpretation for experimental results.



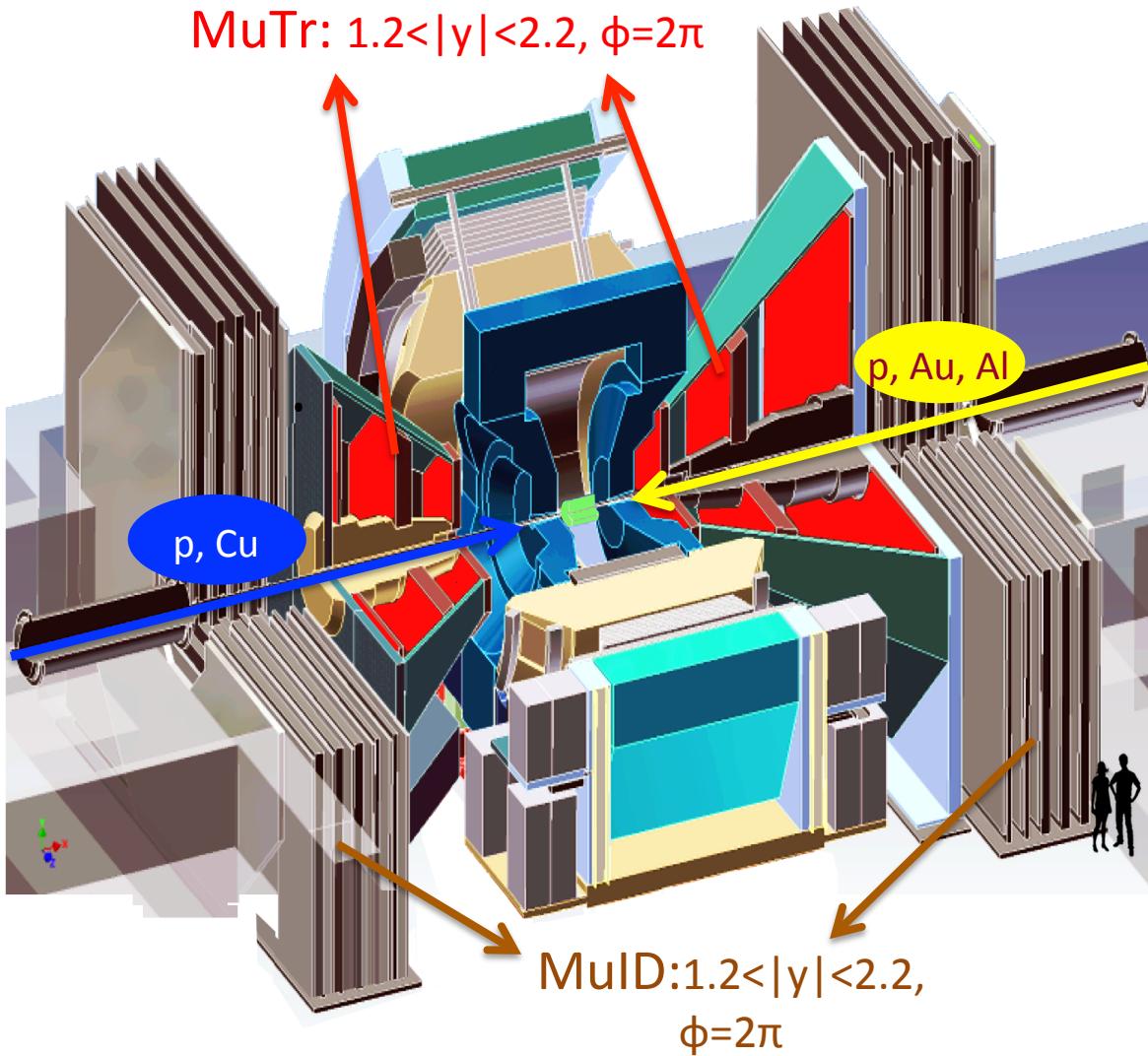
T. Sjöstrand, EPJC17 (2000) 137

Uniqueness at RHIC (II)

- Uniqueness at RHIC
 - accesses complementary kinematics region compared to LHC measurements.



PHENIX detector



Central Arm (Electrons)

- $|\eta| < 0.35$
- $\Delta\varphi = \pi$
- Tracking: DC, PC, VTX
- eID: RICH, EMcal

Forward Arms (Muons)

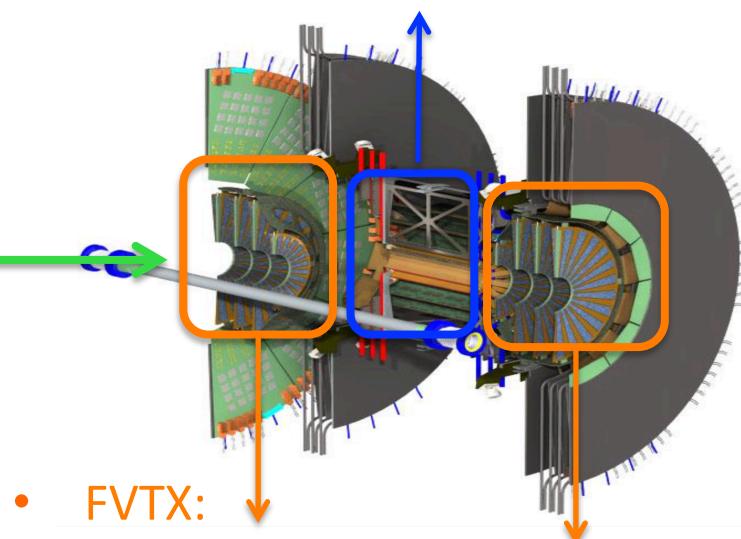
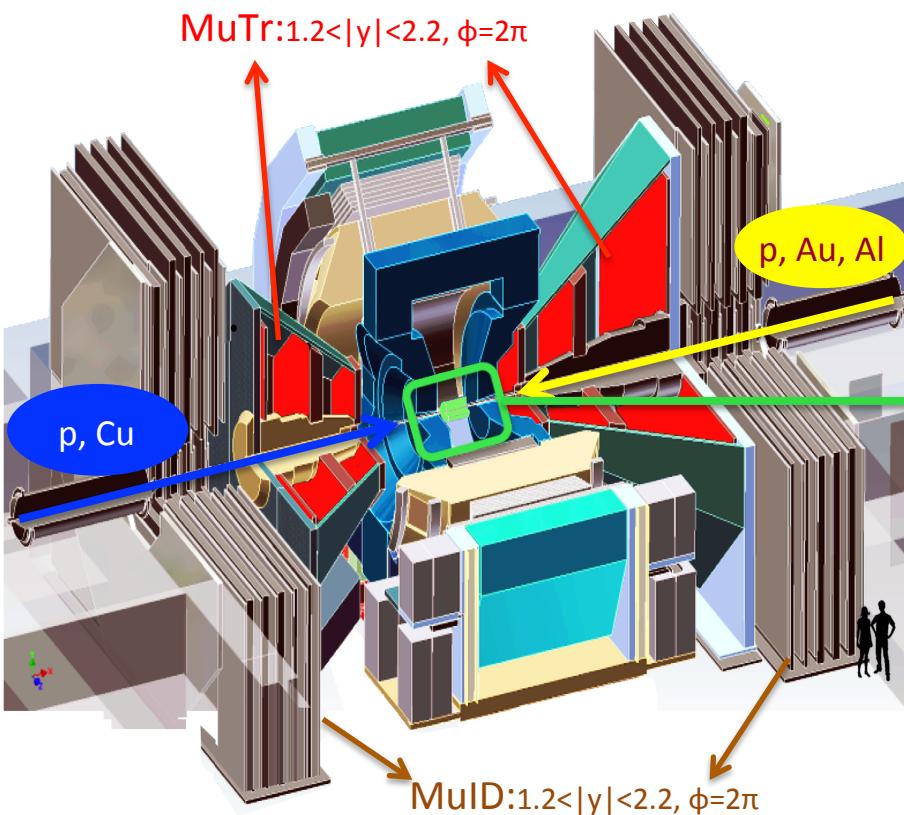
- $1.2 < |\eta| < 2.2$
- $\Delta\varphi = 2\pi$
- ~ 10 interaction length absorber
- **MuTr** (Tracking: wire chamber), **FVTX**
- **MuID**: muon identification detector

Silicon Vertex Detectors of PHENIX

- The silicon vertex detectors: **VTX**(installed since 2011) and **FVTX**(installed since 2012) make the new heavy flavor measurement possible in p+p, p+Al, p+Au, Cu+Au and Au+Au collisions.

- VTX:**

- With $|y| < 1.2$ and $\phi \approx 2\pi$ coverage.
- provide precise vertex and tracking measurements for $D, B \rightarrow X + e$.

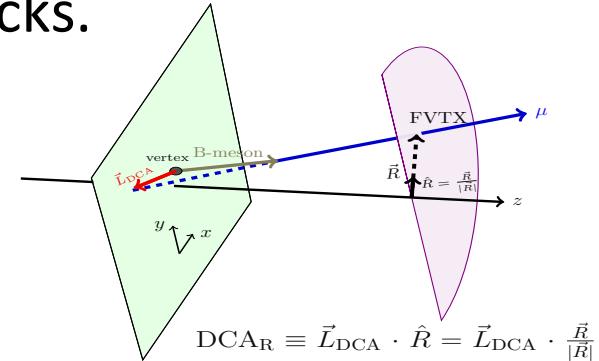
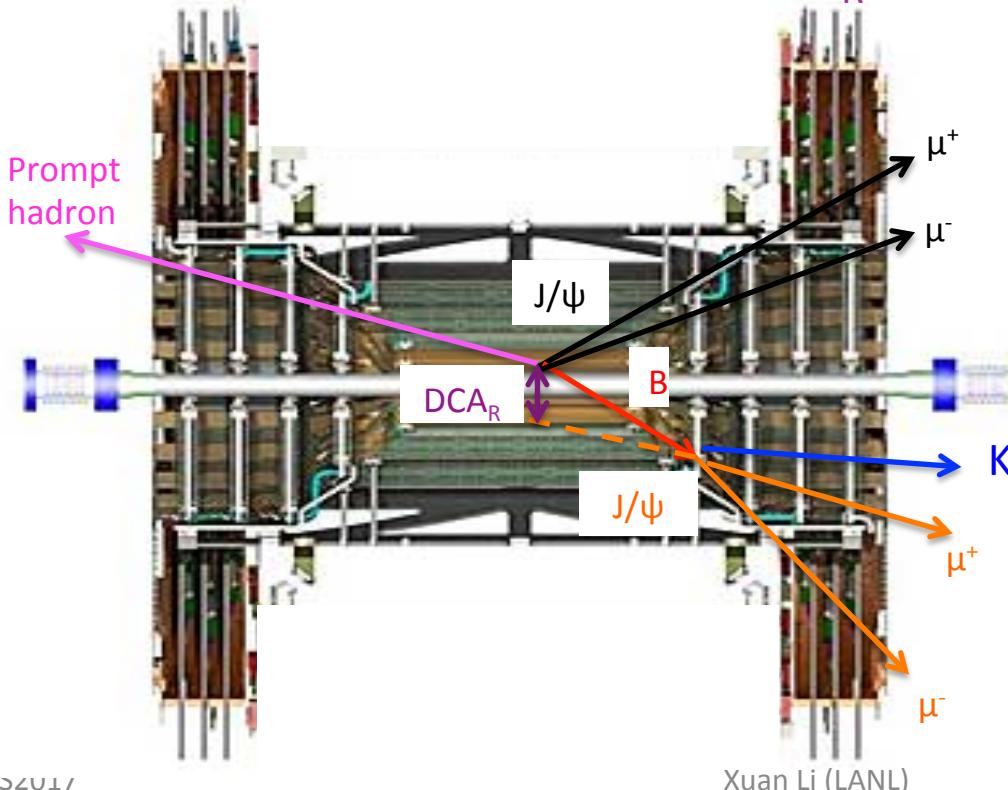


- FVTX:**

- With $1.2 < |y| < 2.2$ and $\phi = 2\pi$ coverage.
- provide precise tracking and Distance of Closest Approach measurements for $B \rightarrow J/\psi$ and D, B separation.

B meson measurement at forward rapidity

- B hadron decay length ($c\tau$), about the size of hair diameter:
 - $c\tau(B^0)=455\mu\text{m}$, $c\tau(B^\pm)=491\mu\text{m}$.
- B hadron is further boosted at forward rapidity, allowing measurements down to $p_T = 0$.
- FVTX can precisely determine the Distance of Closest Approach along the radial projection (DCA_R) of tracks.

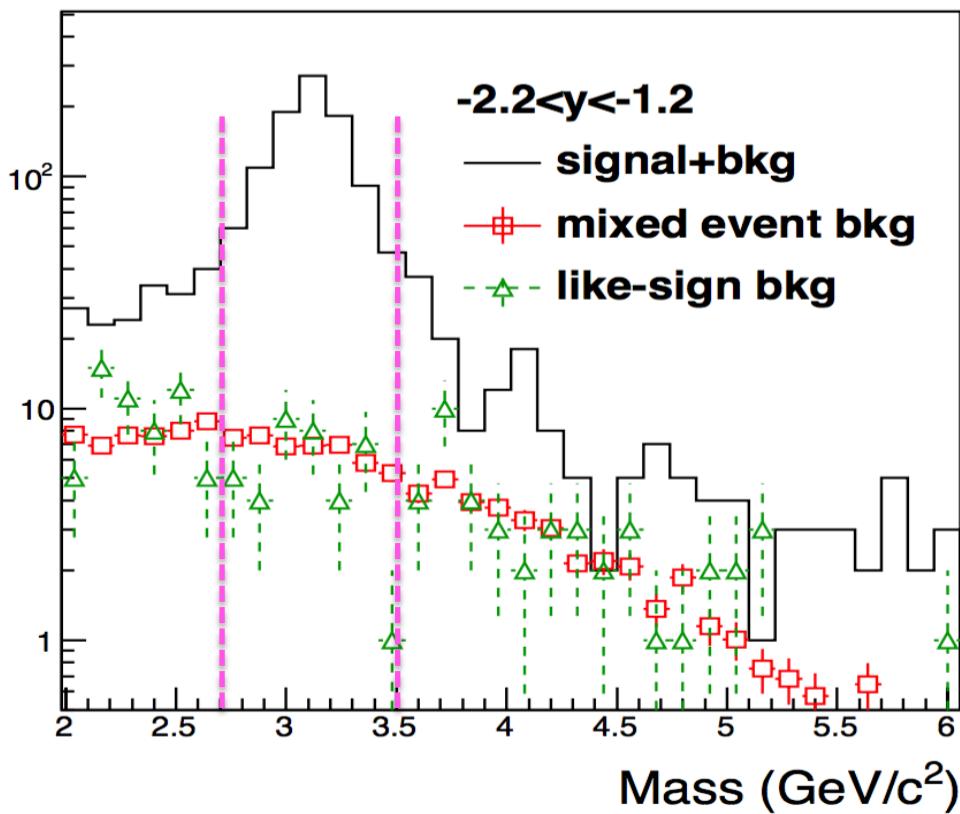


- Different shapes of DCA_R of prompt particles and decayed particles make the separation of B decayed J/ψ and prompt J/ψ feasible.

How to determine the J/ ψ from B-meson decay?

- In p+p collisions, e.g. 510 GeV p+p data:
 - 1) Identify the J/ ψ candidates from di-muon mass spectrum after applying quality cuts.

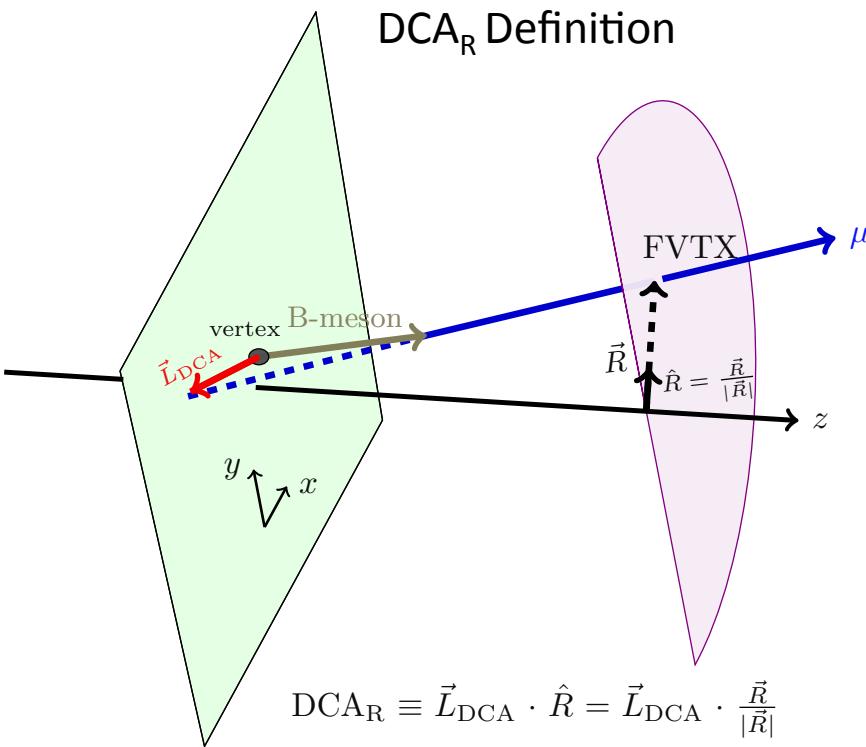
2012 510 GeV p+p data



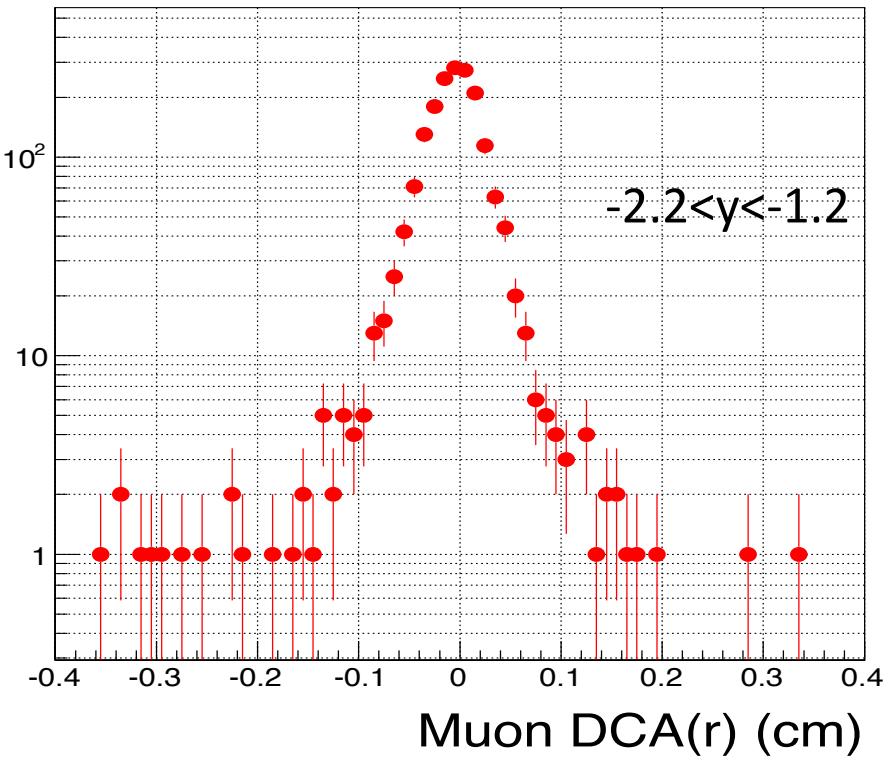
- Clear J/ ψ peaks are found in p+p data.
- Large signal to combinatorial background ratio (11:1) within the J/ ψ region.

How to determine the J/ψ from B-meson decay?

- In p+p collisions:
 - 2) After select good J/ψs, require the muon track of di-muon pairs matching to the FVTX and measure the DCA_R .



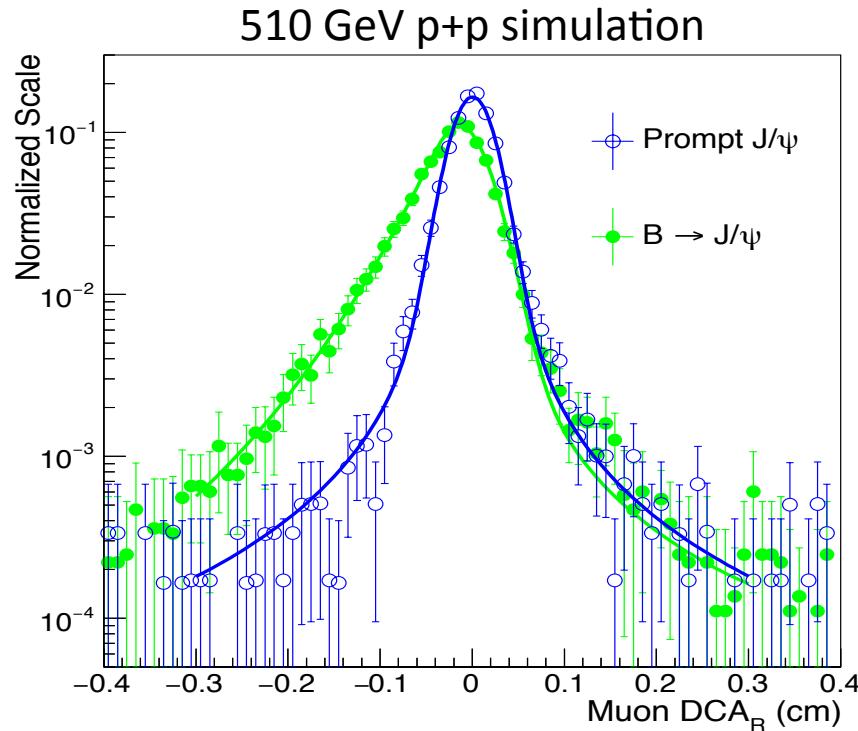
2012 510 GeV p+p data



- Hints of asymmetric in muon DCA_R shapes.

How to determine the J/ ψ from B-meson decay?

- In p+p collisions:
 - 3) Signal determination: generate prompt J/ ψ and B to J/ ψ events in full simulation (PYTHIA+GEANT+RECO) for p+p with realistic vertex and dead maps etc.



- Obvious muon DCA_R shape difference between prompt J/ ψ and B to J/ ψ .

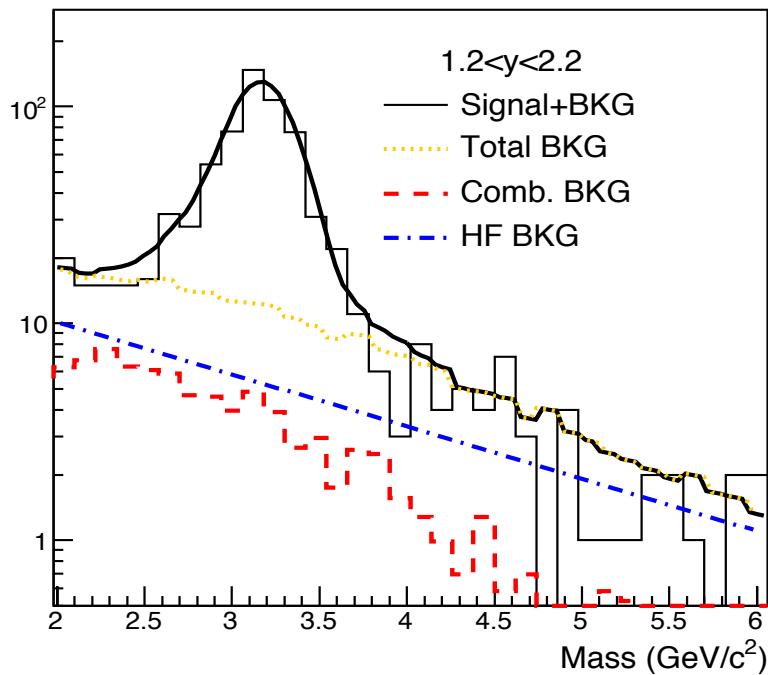
How to determine the J/ ψ from B-meson decay?

- In p+p collisions:

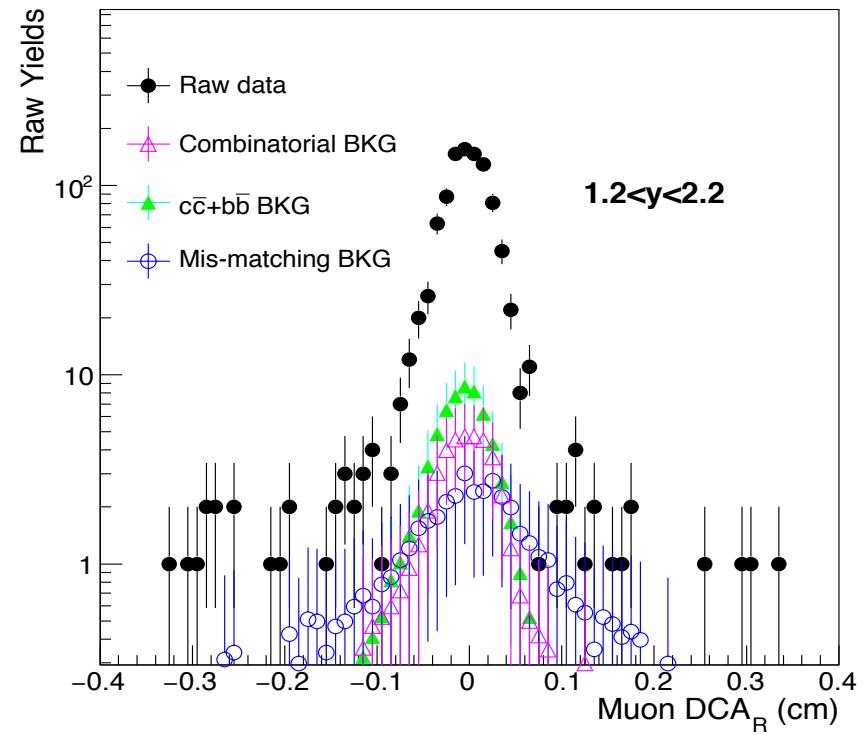
- 4) Determine various background components:

combinatorial, FVTX-MuTr mis-matching and HF continuum backgrounds.

HF continuum background
determined from mass fit



2012 510 GeV p+p collisions

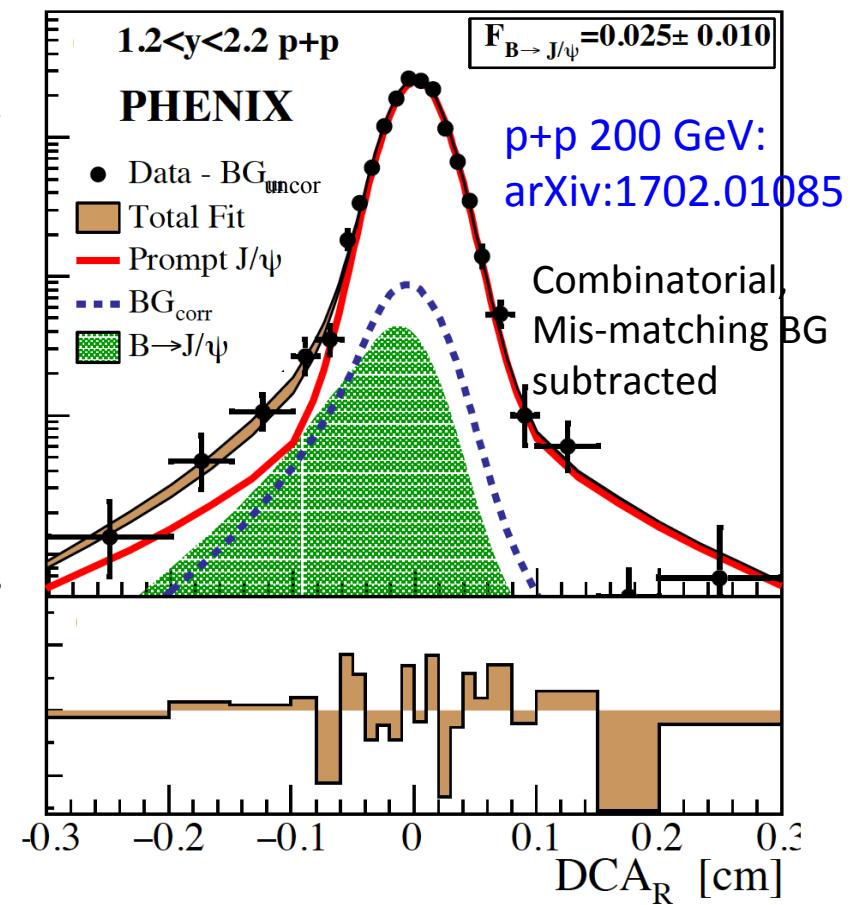
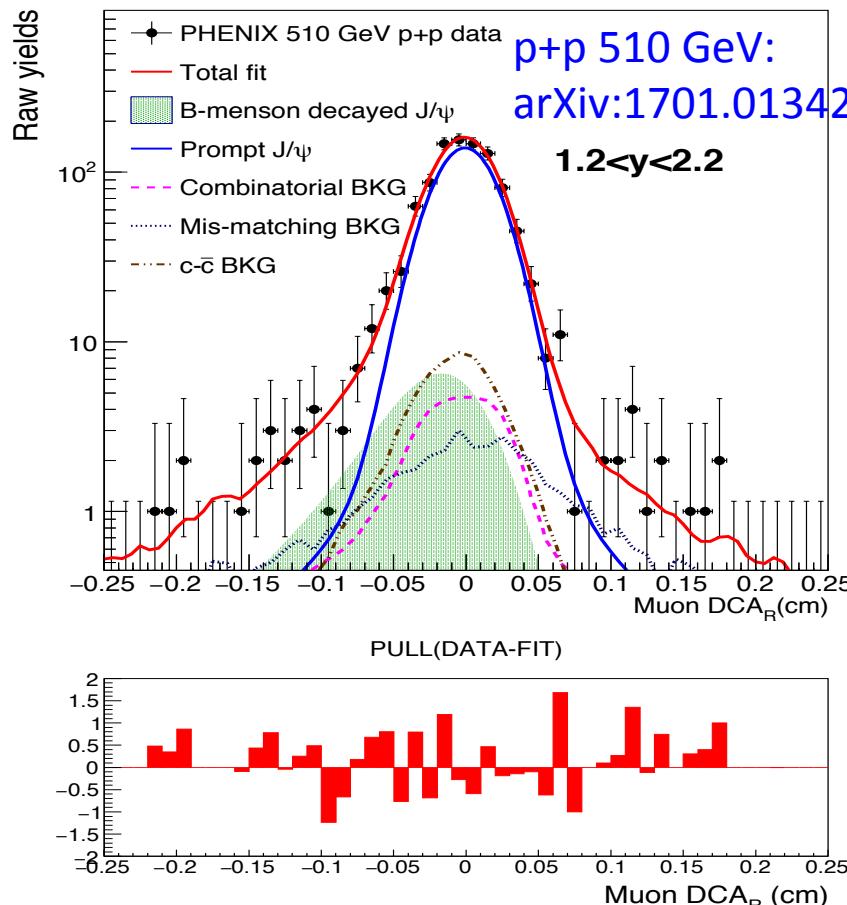


- Backgrounds are well determined.

How to determine the J/ψ from B-meson decay?

- In p+p collisions:

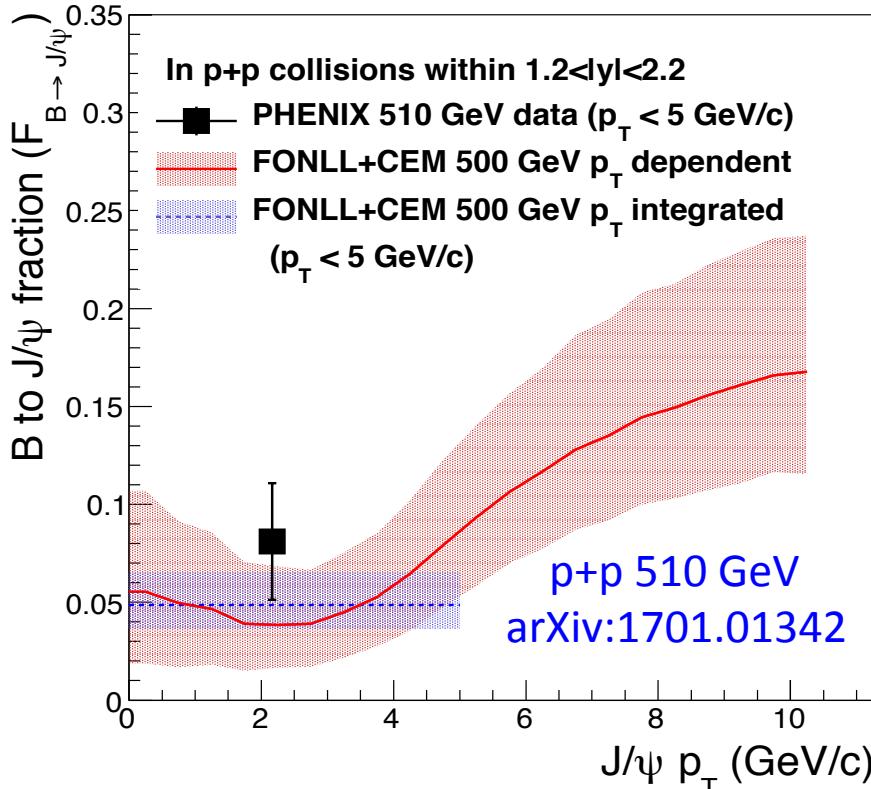
- 5) Fit on DCA_R in data to simultaneously determine the **prompt J/ψ** and **J/ψ from B-meson decay** yields and extract the B to J/ψ fraction.



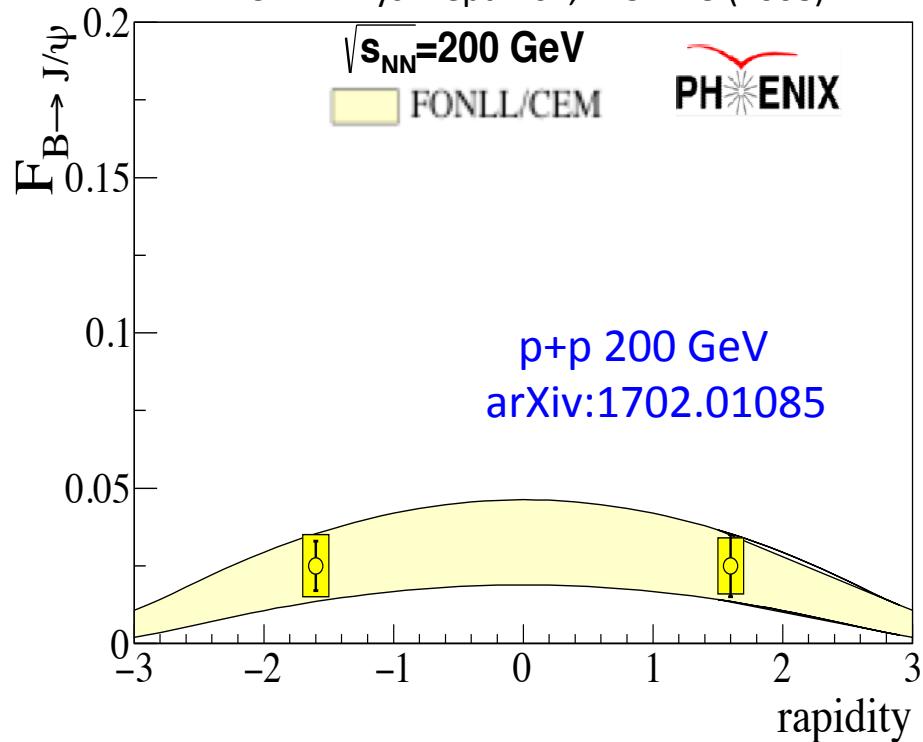
$B \rightarrow J/\psi$ fraction in p+p collisions

$$F_{B \rightarrow J/\psi} = \frac{Yield_{B \rightarrow J/\psi}}{Yield_{inclusive J/\psi}}$$

FONLL+CEM: Phys. Rev. C 87, 014908 (2012)



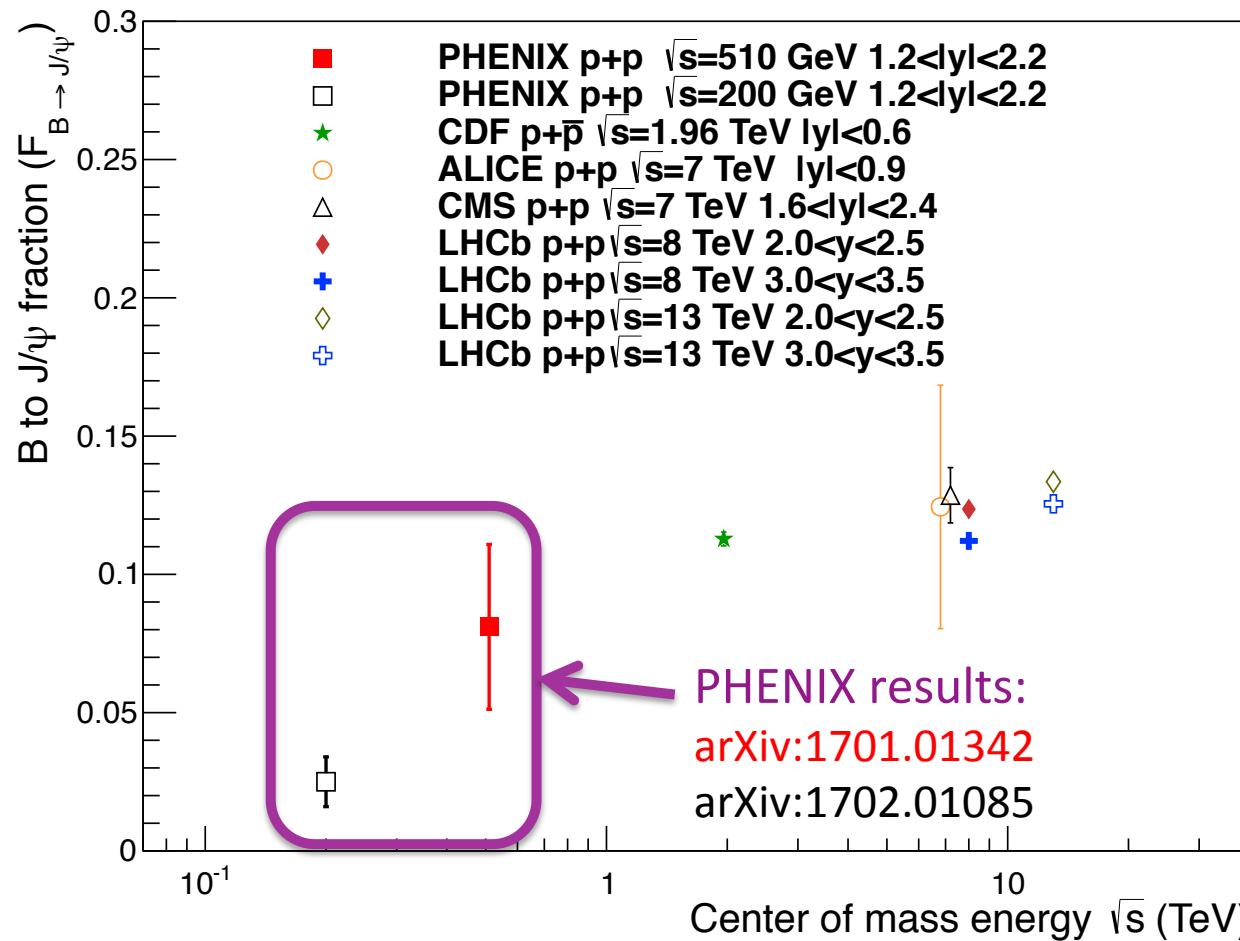
FONLL: JHEP 05, 007 (1998)
CEM: Phys. Rept. 462, 125–175 (2008)



- The FONLL+CEM model calculations are in reasonable agreement with the forward $B \rightarrow J/\psi$ fraction measured at PHENIX in 510 and 200 GeV p+p collisions.

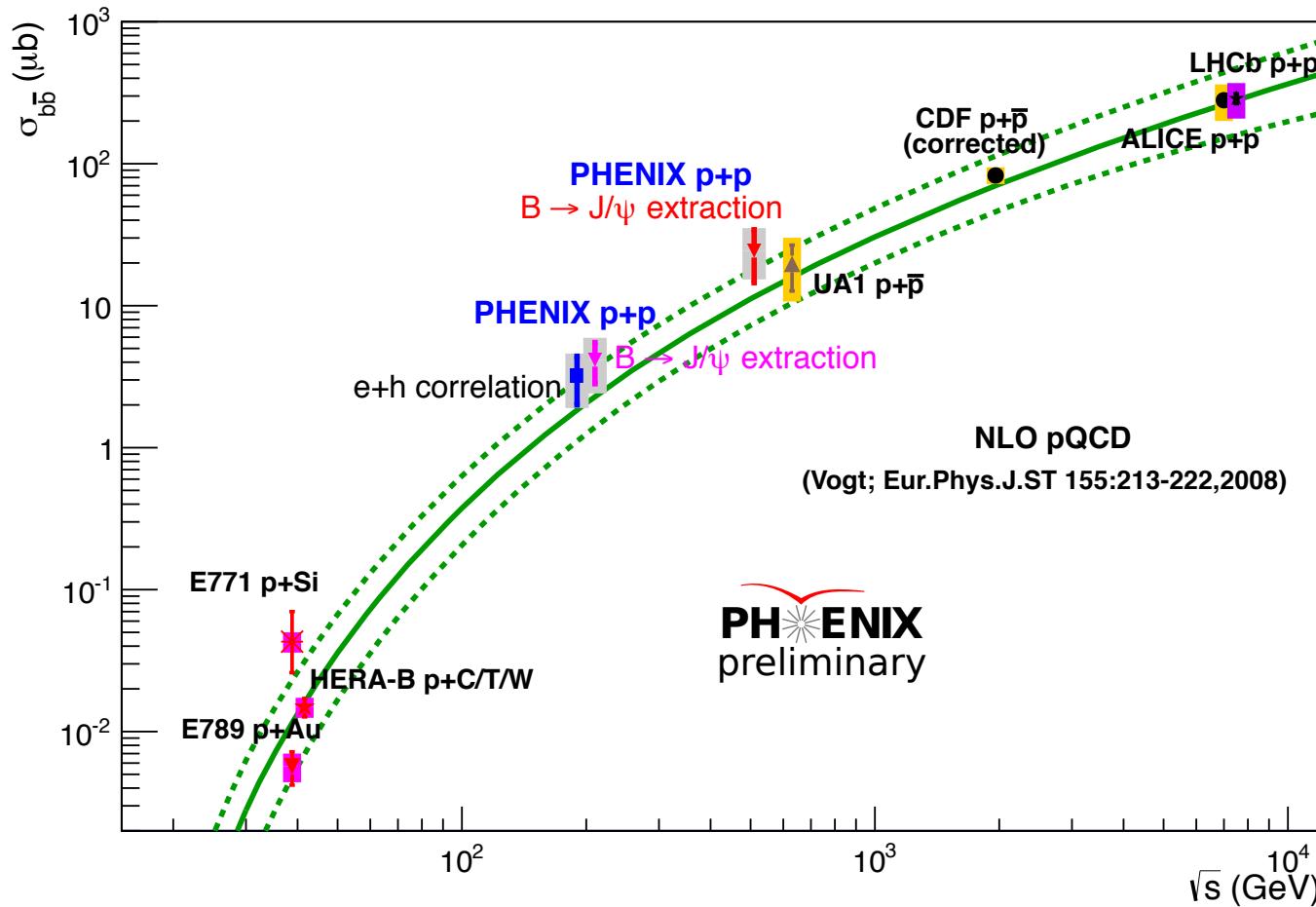
Center of mass energy dependent $B \rightarrow J/\psi$ fraction

- A smooth energy dependence is found from 0.2 to 13 TeV p+p (p+pbar) collisions for $B \rightarrow J/\psi$ fraction measured with integrated J/ψ p_T .



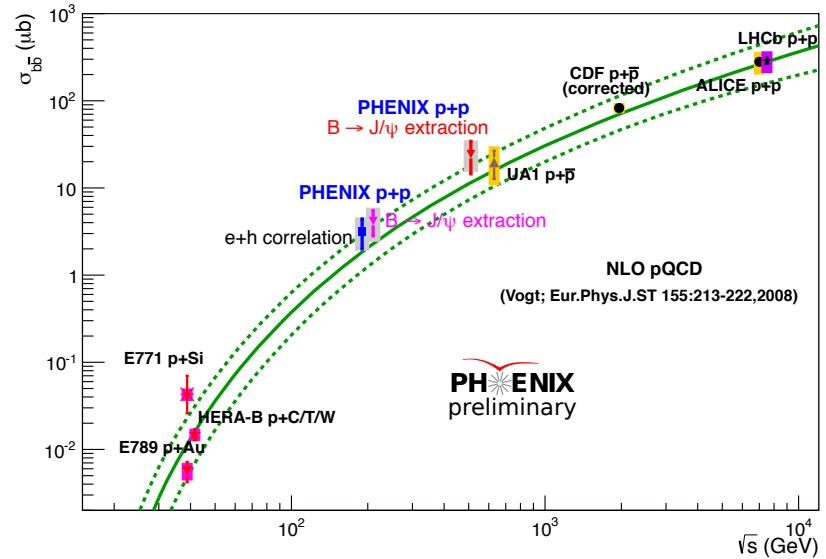
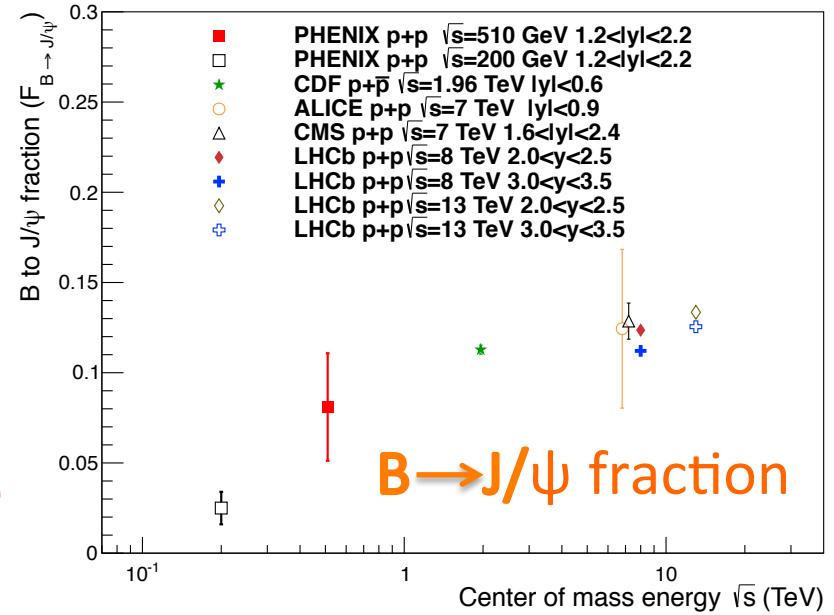
Center of mass energy dependent $b\bar{b}$ cross section

- The NLO pQCD predictions are in reasonable agreements with the extracted $b\bar{b}$ cross section results based on the $B \rightarrow J/\psi$ fractions measured in 200 and 510 GeV p+p collisions.



Summary

- B to J/ ψ fraction (arXiv: [1701.01342](https://arxiv.org/abs/1701.01342), [1702.01085](https://arxiv.org/abs/1702.01085)) in p+p collisions measured at PHENIX together with the CDF and LHC results presents a smooth energy dependence from 0.2 to 13 TeV.
- The extracted bottom cross section in p+p collisions at 200 and 510 GeV indicates a smooth transition for the bottom production from low to high energy.



Outlook

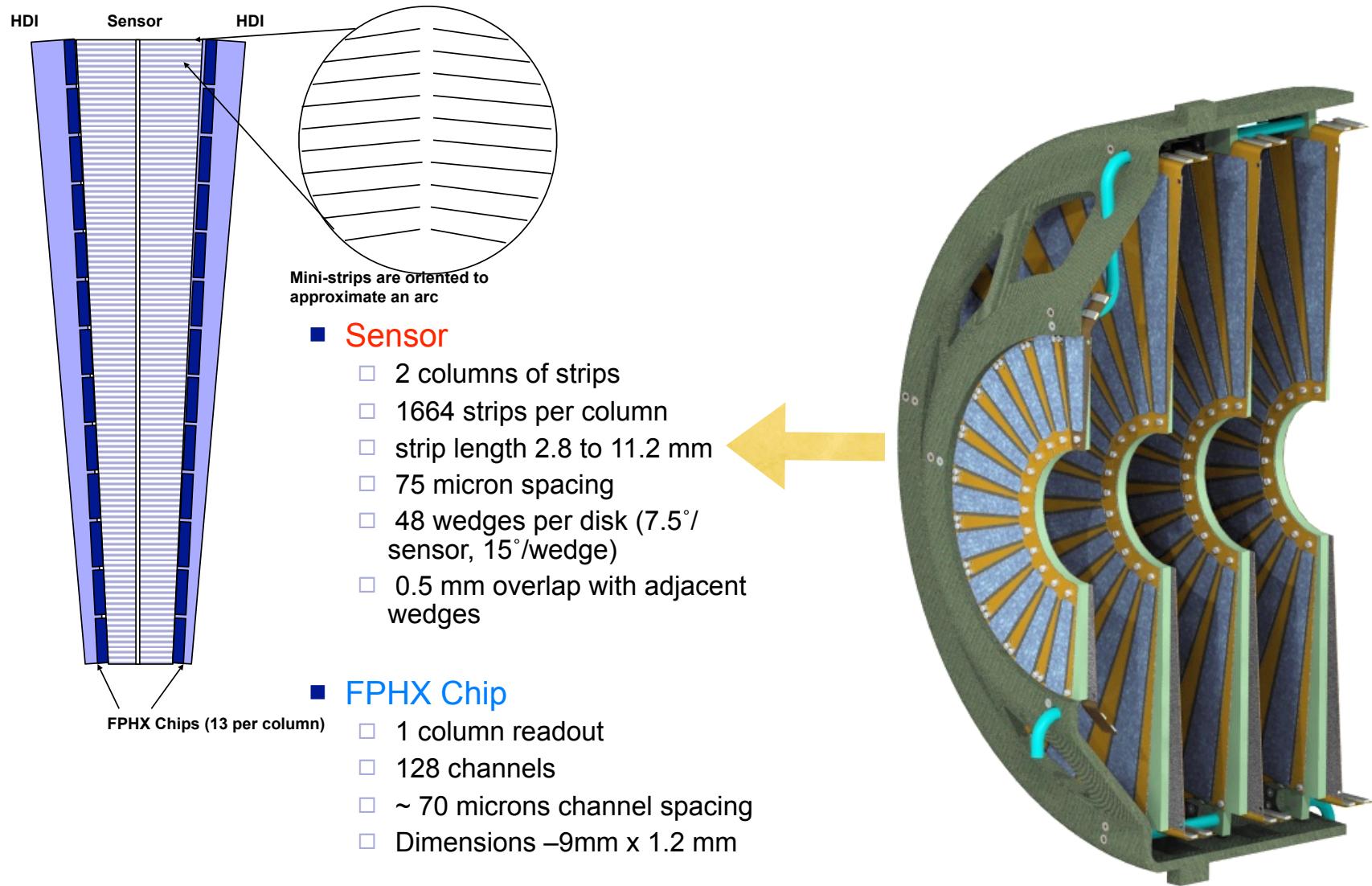
- Much larger statistics measurements of semi-leptonic decay from D and B-mesons are coming up.



More to explore!

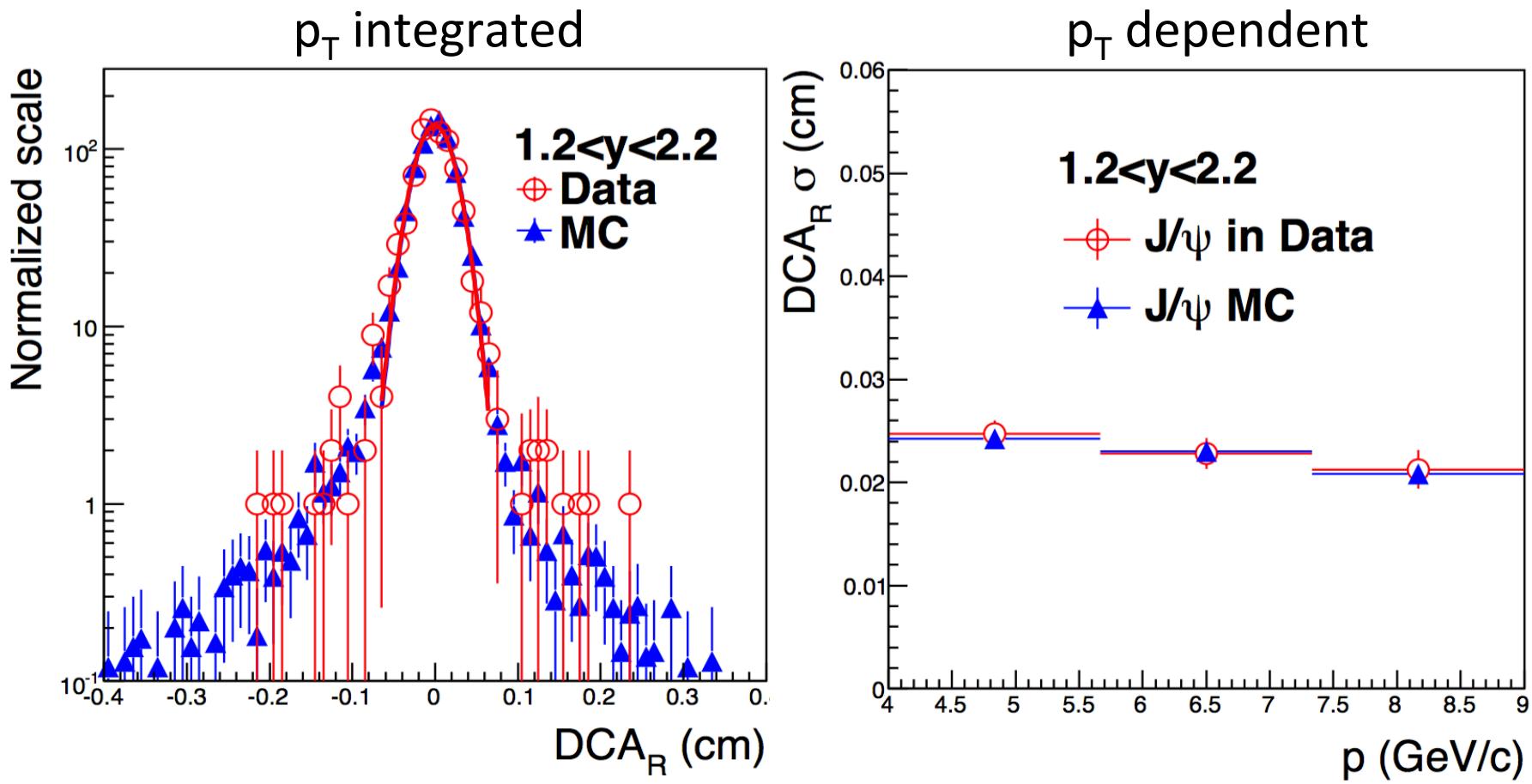
Backup

The Forward Vertex Detector (FVTX)



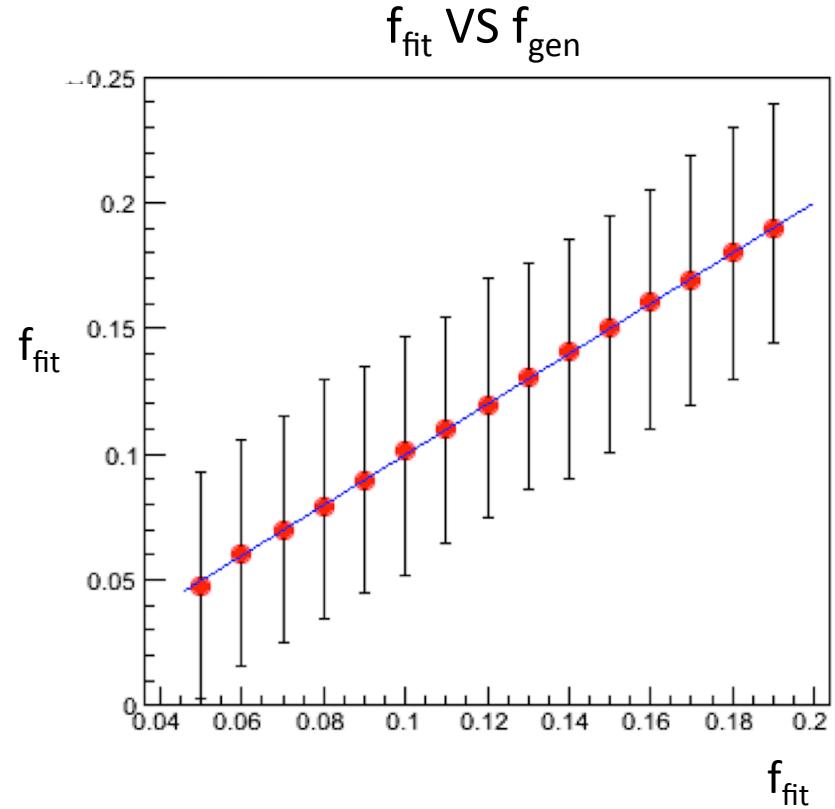
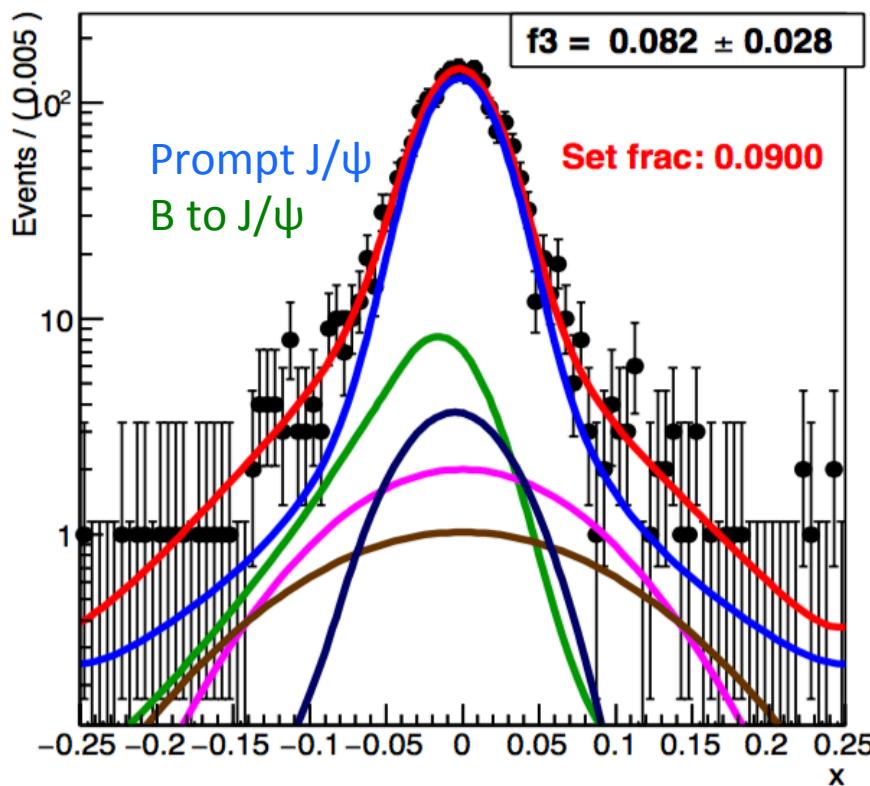
How to determine the J/ ψ from B-meson decay?

- In p+p collisions:
 - 3) Signal determination: DCA_R resolution in data can be well reproduced in simulation for the inclusive J/ ψ sample.



Test the fit package in Toy MC

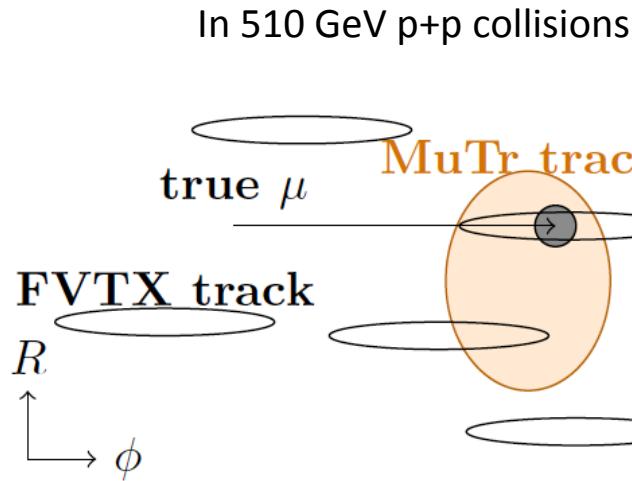
- Generate pseudo-data according to the shape of foreground and background. Use the same fit packages applied in data.



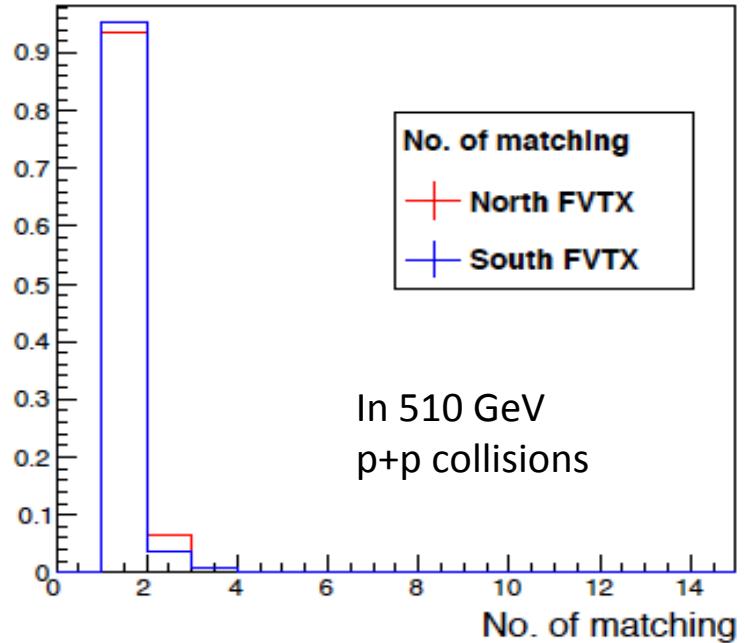
- Good linearity between generated and B to J/ ψ ratio.
- Final results from data are under collaboration review.

FVTX-MuTr mis-matching background determination

- For one MuTr track, there is a probability of finding more than one FVTX track within the matching window.



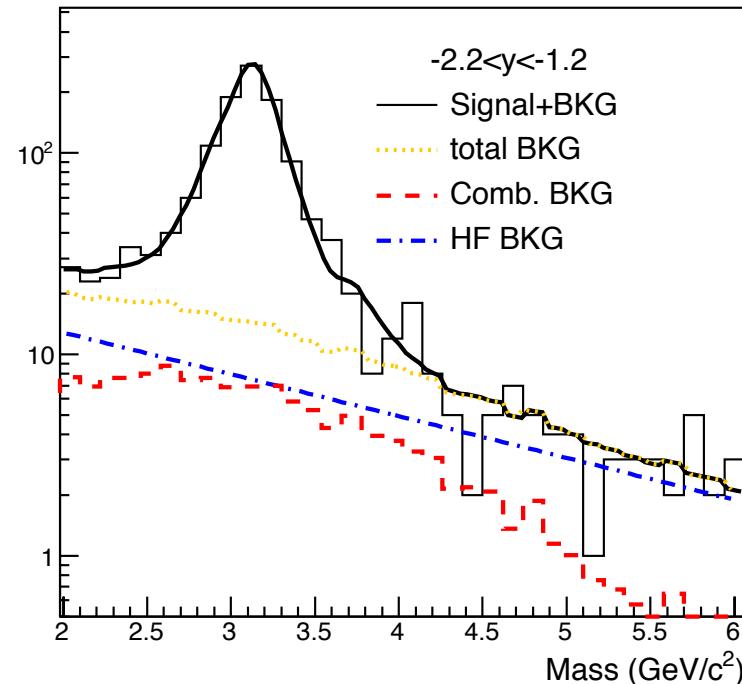
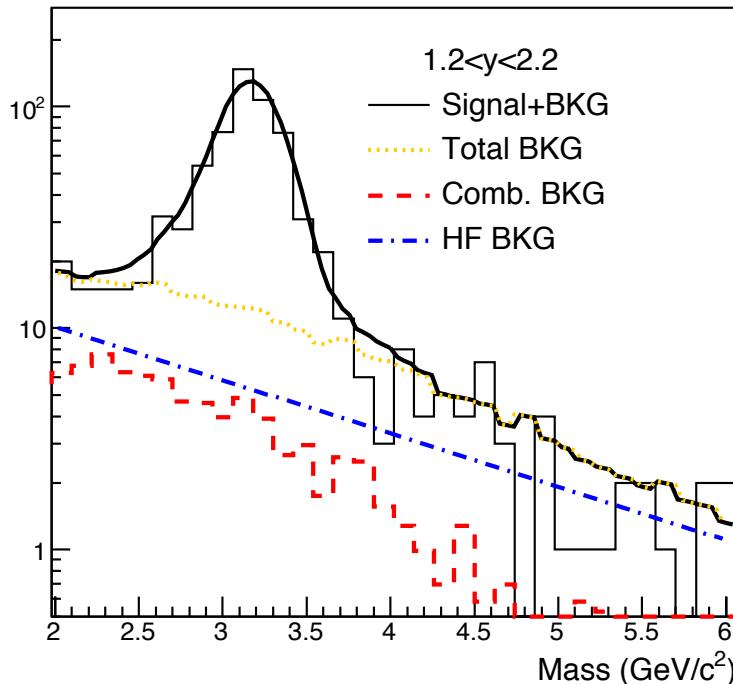
No. of FVTX tracklets matched to MuTr Track



- In p+p collisions, the probability to have more than one FVTX track matched with the MuTr track is around or less than 5%.

HF continuum background determination (510 GeV p+p)

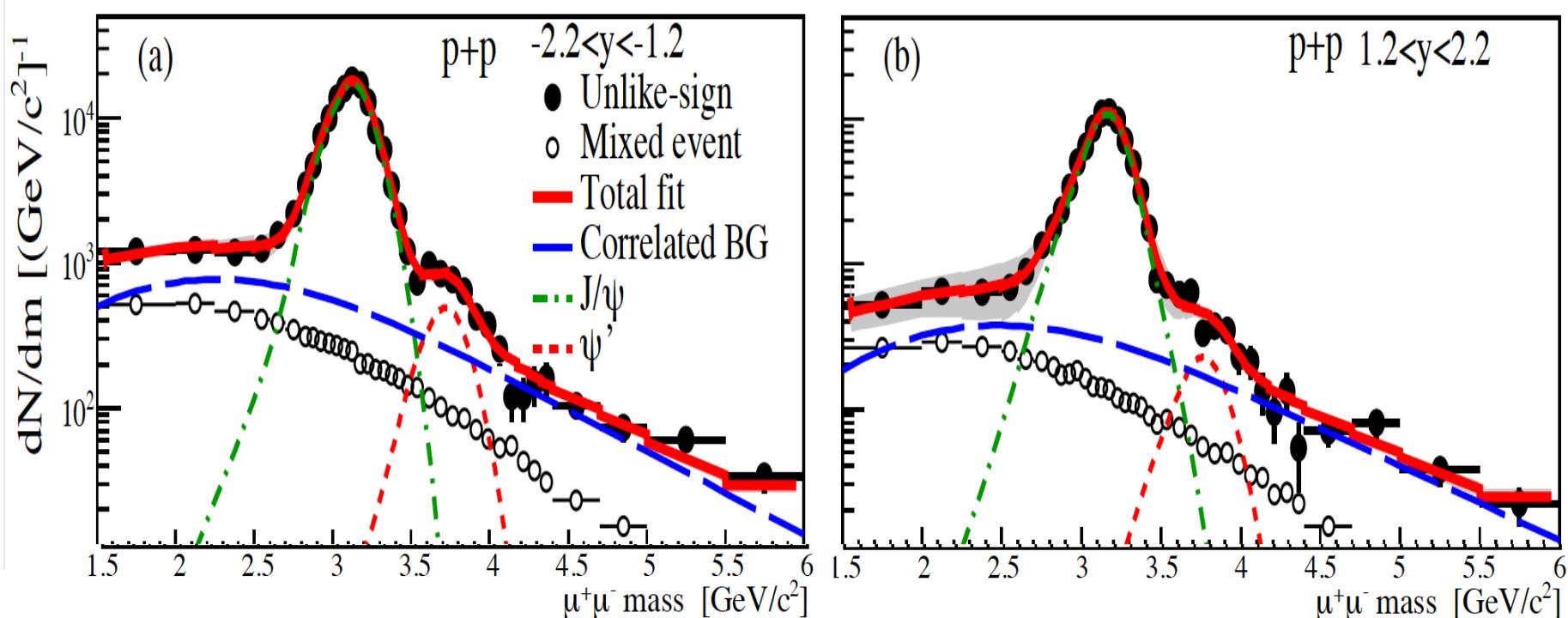
- Fit the di-muon mass to extract the HF continuum background.



- Total background consists of HF continuum background and mixed event background.
- HF continuum background is comparable with the mixed event background within the mass cut window.

HF continuum background determination (200 GeV p+p)

- Fit the di-muon mass to extract the HF continuum background.



- Total background consists of HF continuum background and mixed event background.
- HF continuum background is comparable with the mixed event background within the mass cut window.

Analysis strategy for the B to J/ ψ ratio measurement (III)

- Fit on DCA_R in data to simultaneously determine the **prompt J/ ψ** and **J/ ψ from B-meson decay** yields and extract the B to J/ ψ fraction.

